

Reevaluation of the Taxonomic Status of a Poorly Known Gecko, *Gekko liboensis* (Reptilia: Squamata)

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Abstract *Gekko liboensis* Zhou and Li, 1982 is a poorly known gecko originating from Libo, Guizhou, southern China. Since the original description based on a single female from Libo, only three specimens (two females and one juvenile) have been reported from the type locality. Because of its close morphological resemblance to *G. hokouensis* Pope, 1927, *G. liboensis* is required to be reevaluated for its taxonomic status by studies based on additional specimens. Here we report for the first time the morphological features of 31 newly obtained specimens of *G. liboensis* from type locality and others, including males, and compare them with those of related species, chiefly on the basis of information from the literature. In addition, specimen-based comparisons were also made with *G. hokouensis* and an undescribed cryptic species known from the Ryukyus Islands, Japan. Results showed that the species is distinguished from its congeners in having a larger body size (60–91 mm), 0–2 small internasals, 10–13 supralabials, 10–13 infralabials, smooth enlarged tubercles present on the dorsum forming 4–10 irregular rows at the midbody but absent on the four limbs and tail, both fingers and toes without developed interdigital webs, a single cloacal spur on each side, and 10–12 precloacal pores in males. It most resembles *G. hokouensis* and its cryptic species but is clearly differentiated by having a larger body size, a predominantly absent internasal, fewer number of dorsal tubercle rows, larger number of precloacal pores, and conspicuous white marks on the dorsum and head. Judging from these results, we confirmed the taxonomic validity of *G. liboensis*. In addition, the geographic distribution of this gecko on the basis of obtained data was briefly discussed.

Keywords China, East Asia, Gekkonidae, *Gekko japonicus* group, taxonomy, morphology

1. Introduction

Gekko liboensis Zhou and Li, 1982 is a gekkonid lizard described on the basis of a single female collected from Libo, Guizhou Province, southern China (Zhou and Li, 1982). Subsequent to the original description, only three specimens (two females and one juvenile) have been reported from the same locality (Zhao *et al.*, 1999), and thus, the morphological features of the male, range of variation, and other biological aspects of this species are virtually unknown. Although Xu *et al.* (2007) reported

this species in their list of the herpetofauna of Maolan and Chishui, Guizhou, the record from Chishui, which is >350 km northwest of the type locality, was not based on any specimens and may be erroneous because of misidentification (Wei Gang, personal communication).

Zhou and Li (1982) described this species on the basis of a series of characteristics: large body size [snout–vent length (SVL) of 85 mm]; absence of internasal (IN); approximately 40 interorbitals (IOs); paired postmental, twice as long as wide, contacted posteriorly by a pair of enlarged scales; 12 supralabials (SPLs); 11 infralabials (ILs); somewhat flattened dorsal tubercles, forming approximately 10 irregular longitudinal rows on the body, absent on four limbs and tail; both fingers and toes having faint interdigital webs; and single cloacal spur on each

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side. However, most of these character states are shared with *G. hokouensis* Pope, 1927, another species of *Gekko* occurring in the eastern part of China (including mainland China and Taiwan) and Japan (Zhou *et al.*, 1982; Zhao *et al.*, 1999). Thus, Zhao and Adler (1993), Günther (1994), Kluge (2001), and Henkel and Schmidt (2003) listed *G. liboensis* as a junior synonym of *G. hokouensis*, whereas Kluge (1993), Bauer (1994), Welch (1994), Matsui and Ota (1995), Zhao *et al.* (1999), Rösler (2000), and Rösler *et al.* (2006) recognized *G. liboensis* as a valid species.

Rösler *et al.* (2011) assigned *G. liboensis* as a member of the *Gekko japonicus* species group and noted the several morphological differences of this form from *G. hokouensis* by summarizing literature information, including larger maximum SVL (85 vs. 70 mm), absence of INs, greater number of IOs (40 vs. 30–33), flat dorsal tubercles, fewer dorsal tubercle rows (DTRs; 10 vs. 12–18), and fewer lamellae below the forth toe (9 vs. 15–18). Considering the fact that the data collected for *G. liboensis* are from a single specimen, reevaluation of the character states using a larger sample is needed. Furthermore, Toda *et al.* (2001) reported the existence of a possibly undescribed species from the Ryukyu Islands, Japan, which shares identical states in all morphological diagnostic characteristics with *G. hokouensis* but is genetically distinctive, even in a sympatric area (henceforth referred to as *Gekko* sp. 1). Considering such a future taxonomic problem, thorough revision of the taxonomic status of *G. liboensis* is required to reevaluate its validity. For around 30 years, however, no study has been attempted to elucidate the taxonomic validity of *G. liboensis* because of the deficiency of available specimens, particularly those of male individuals (Rösler *et al.*, 2011).

Through the course of our field surveys in Guizhou Province and Guangxi Zhuang Autonomous Region, southern China, we collected many geckos, including males, whose morphological features agreed well with the original description of *G. liboensis*. Based on these new specimens, we conducted morphological examinations of this form for comparison with other congeneric species, particularly with the morphologically similar *G. hokouensis* and the putative undescribed species *Gekko* sp. 1.

2. Materials and Methods

2.1 Sampling Field surveys were conducted in Guizhou Province and Guangxi Zhuang Autonomous Region, southern China in August 2014. A portion of the

specimens (six males and three females) were fixed in 10% formalin and then transferred to 70% ethanol for gonad examination. After that they were deposited in the collections of the Chengdu Institute of Biology (CIB). The remaining specimens were kept alive for future behavioral examinations and will be also deposited in the collections of CIB.

2.2 Morphological examinations Sex of individuals was determined based on the presence or absence of precloacal pores (PPs) and the swollen tail base, which are found only in males (Bauer, 2013). Two females and one male of relatively small size (around 60 mm of SVL) in our sample were subjected to gonadal observation to determine sexual maturity. One female and five males that were seemingly large enough to attain sexual maturity were also examined for comparison. Evaluation of gonad condition was made following the criteria provided by Okada *et al.* (1992).

A total of 31 specimens including males and females mentioned above were examined morphologically. Because most adult geckos of both sexes needed to be kept alive for future study, we conducted scale counts and other morphological observations on live specimens. This treatment might induce slight difference in mensural values when compared to values taken after fixation, but it was not the case for meristic characters because scale counts were carefully conducted using a microscope and close-up photography when necessary. SVL and tail length (TL) were measured to the nearest 0.1 mm using a caliper. Regenerated tails were not measured. SVL was compared between adult males and females by Mann–Whitney *U*-test. Meristic characteristics measured included the number of IOs, DTRs around midbody, the number of SPLs, the number of ILs, the number of INs, the number of subdigital lamellae under first toe (SLI), the number of subdigital lamellae under the forth toe (SLIV), the number of precloacal pores in males (PP), the number of dorsal dark bands (DB), and the number of caudal dark band (CB). We counted the right side for bilateral characteristics.

Morphological data for the present samples were compared with those of other congeneric species. Rösler *et al.* (2011) proposed a six species group within the genus *Gekko* on the basis of molecular phylogeny, body size, scalation, color pattern, and geographic distribution, and assigned all East Asian species including *G. liboensis* into the *Gekko japonicus* species group. In light of such classification, we considered all species belonging to this group for comparisons. Morphological data for these species were collected from available literature (Ota *et al.*,

1989; Toda, 2008; Zhang *et al.*, 2009; Phung and Ziegler, 2011; Rösler *et al.*, 2011; Yang *et al.*, 2012; Nguen *et al.*, 2013; Luu *et al.*, 2014; Ngo *et al.*, 2015). Because of the close morphological resemblance of *G. hokouensis* and *Gekko* sp. 1 to *G. liboensis* (see above), we made additional detailed comparisons using the original unpublished dataset of Toda (2008), in which 170 specimens of *G. hokouensis* and 115 specimens of *Gekko* sp. 1 (see Appendix 1 for the specimen list). The taxonomic identities of these specimens were confirmed by allozyme analysis (Toda, 2008). In comparisons between *G. liboensis* and *G. hokouensis* or *Gekko* sp. 1, we employed the Steel-Dwass test. All statistical tests were performed using R 2.14.0 (R Development Core Team, 2011).

3. Results

3.1 Field collection and incidental data A total of 31 specimens were collected from Libo and Maolan in Guizhou Province, and Nalao in Guangxi Zhuang Autonomous Region (Figure 1A; Table 1). Most of the geckos were collected during the night (20:25–02:57) on rocky cliffs along roads that run through hilly or mountainous regions (Figure 1B and C). One specimen was found during the daytime (10:30) on a rocky cliff in a similar environment but inside a crevice. One specimen from Libo and two from Nalao were collected from vegetation-covered walls of human housing situated adjacent to mountain forests.

In some places where the *Gekko* specimens were collected, gekkonid eggs were found affixed to depressions of the rock surface or inside a crevice, characterized by calcareous shells, an elliptical shape, and two eggs per clutch (Figure 1D). The diameters along the long and short axes of the six eggs (mean $\pm$ SD) were 16.3 ± 0.57 (range 15.6–17.2) mm and 12.4 ± 0.40 (range 12.0–13.0) mm, respectively.

3.2 Redescription of *Gekko liboensis* Scale counts and tubercle conditions of the gecko specimens are listed in Table 2. The characteristics of the specimens were: (1) a medium sized *Gekko* (SVL up to 91.0 mm); (2) the absence of the IN in many cases (Figure 2C); however, 1–2 small INs were present in a few individuals (Figure 3); (3) a nostril touching rostral; (4) 38–46 IOs; a paired postmental, with the length approximately 1.5–2 fold of the width, contacted posteriorly or posterolaterally by 1–2 rows of enlarged scales (Figure 2D); (5) 10–13 SPLs; (6) 10–13 infralabials; (7) smooth enlarged tubercles present on the dorsum (Figure 2F), forming 4–10 irregular rows

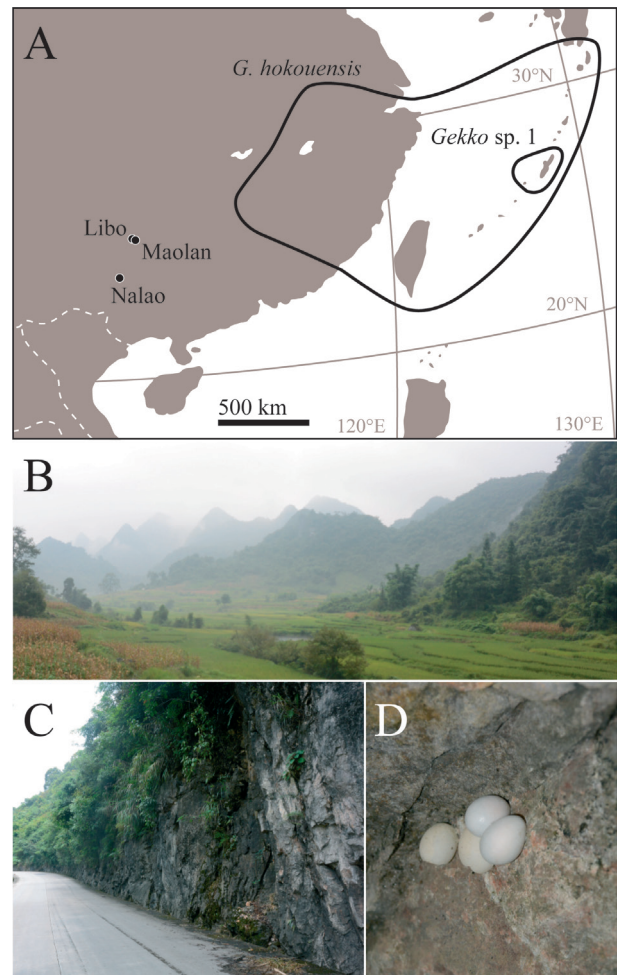


Figure 1 (A) Map showing sampling localities of the *Gekko liboensis*-like form (closed circles) and the known distributional ranges of *G. hokouensis* and *Gekko* sp. 1. (B) Landscape of the habitat of the geckos; Maolan, Guizhou province, southern China. (C) Typical microhabitat of the present form. (D) Two clutches of gekko eggs were found.

at the midbody but absent on the four limbs and tail (Figure 2H); (8) digits dilated, under surfaces covered with single rows of lamellae along their entire lengths; (9) 11–15 SLIs; (10) 11–18 SLIVs; (11) both fingers and toes without developed interdigital webs (Figure 2G); (12) a single cloacal spur on each side; (13) 10–12 PPs in males (Figure 2E); (14) an original tail that is slender shaped and somewhat depressed at the base; and (15) broad and enlarged subcaudals (Figure 2I).

The specimens exhibited a characteristic color pattern as shown in Figure 2A: the color of the dorsal surface of the body is greenish gray or gold, with 7–11 middorsal blotches, each subdivided medially. In most cases, each blotch had many gold flakes on both sides. Conspicuous round-shaped white marks were scattered on the dorsum, sometimes forming irregular transverse bands intervening

the middorsal blotches. On the dorsal surface of the head, relatively small sized white spots occurred with a series of white spots usually forming a “W” shape on the neck. A white stripe ran through the orbit of the eye, with the iris of a gold color, sometimes slightly greenish. White marks occurred on the four limbs, often forming a few transverse bands with irregular outlines. The tail was banded, with dark parts becoming darker and broader posteriorly. The ventral surface of the head and abdomen was creamy with dark dots.

3.3 Gonadal observation Gonads of nine specimens were measured as 60.9, 65.9, 68.4, 72.1, 78.6, and 86.0 mm in SVL of six males, and 58.3, 60.6, and 79.8 mm in SVL of three females. Among the females, the largest individual possessed three (left) and two (right) yolked ovarian follicles and flaccid oviducts, whereas the two females smaller than 60.6 mm in SVL possessed neither oviductal egg nor yolked ovarian follicle, and their oviducts were not flaccid. Similarly, five large males had well-developed epididymides with apparently distinct tubules, whereas the smallest male had undeveloped epididymides characterized by the absence of convoluted tubules. Based on these results, we considered the three specimens around 60 mm in SVL to be juveniles and the remaining 28 specimens larger than 65 mm in SVL to be adults. In adults, no significant difference in SVL and TL between sexes was detected (Mann–Whitney *U*-test, $P = 0.452$ in SVL, $P = 0.512$ in TL; Table 2).

3.4 Comparison of key characteristics with *G. hokouensis* and *Gekko* sp. 1 In comparison with *G. hokouensis* and *Gekko* sp. 1 using the literature information, the present form differed by having a larger SVL and more PPs, although their ranges slightly overlapped (Table 3).

In quantitative comparison, the number of INs was significantly lower in *G. liboensis* than that in either *G. hokouensis* or *Gekko* sp. 1 (Steel–Dwass test, $P < 0.0001$ in *G. liboensis* vs. *G. hokouensis* and *G. liboensis* vs. *Gekko* sp. 1). IN was absent in 77% of *G. liboensis*, but only in 17% of both *G. hokouensis* and *Gekko* sp. 1 (Figure 3). The SVL was significantly larger in *G. liboensis* than in either *G. hokouensis* or *Gekko* sp. 1 (Steel–Dwass test, $P < 0.0001$ in *G. liboensis* vs. *G. hokouensis* and *G. liboensis* vs. *Gekko* sp. 1; Figure 4). The range of SVL did not overlap between *G. liboensis* and *G. hokouensis*, but overlapped between *G. liboensis* and *Gekko* sp. 1. The number of PPs was significantly higher in *G. liboensis* than in either *G. hokouensis* or *Gekko* sp. 1 (Steel–Dwass test, $P < 0.0001$ in *G. liboensis*

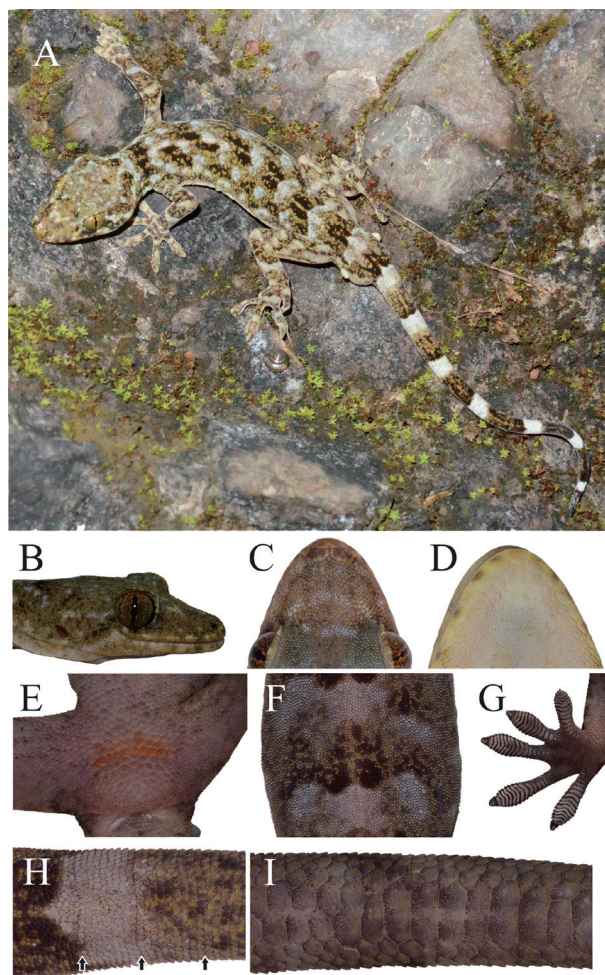


Figure 2 Living *Gekko liboensis* specimen (CIB101251). (A) The male in natural habitat. (B) Lateral view of the head. (C) Rostral without internasal. (D) Mental with enlarged postmental scales. (E) Ten precloacal pores with orange colored secretion. (F) Dorsum at midbody portion with somewhat flattened enlarged tubercle. (G) Lamellae beneath the toes of the right foot. (H) Dorsal view of tail near the base without tubercles. Arrowheads indicate each segment. (I) Median enlarged subcaudal scales.

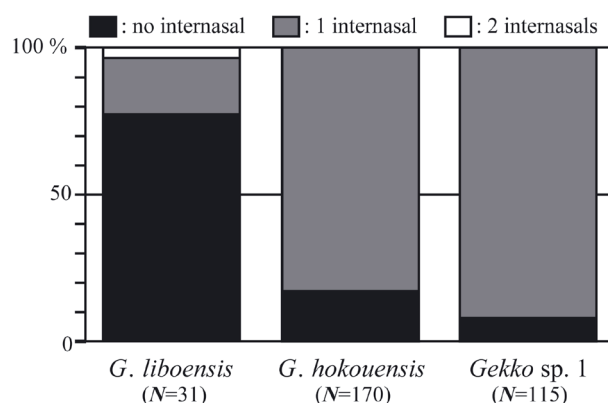


Figure 3 Bar graphs showing number of internasals (INs) in *Gekko liboensis*, *G. hokouensis*, and *Gekko* sp. 1. Black, gray, and white bars show percentage of individuals that have 0, 1, and 2 INs, respectively.

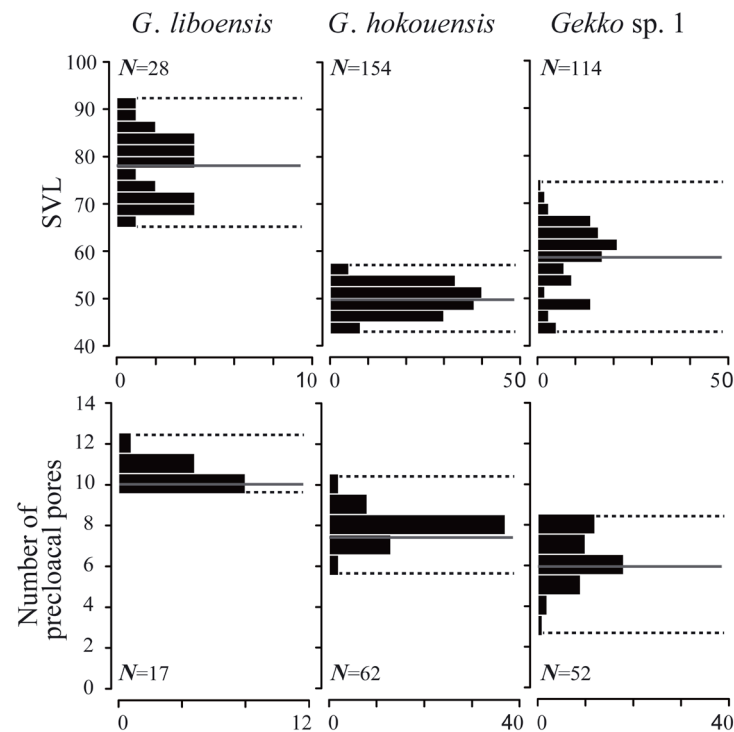


Figure 4 Histograms of snout-vent length and number of precloacal pores in *Gekko liboensis*, *G. hokouensis*, and *Gekko* sp. 1. Solid and Dashed lines show means and ranges, respectively.

Table 1 Localities of *Gekko liboensis* examined in this study. *N* indicates the total number of individuals; number of males/females/juveniles are shown in parentheses. Latitude, longitude, and elevation were recorded by datum WGS84.

Site	<i>N</i>	Latitude	Longitude	Elevation (m)
Libo, Guizhou	1 (0/1/0)	25°24' N	107°52' E	424
Maolan, Guizhou	27 (16/8/3)	25°17' N	107°59' E	578–799
Nalao, Guanxi	3 (1/2/0)	24°25' N	107°22' E	473

Table 2 Mensural and meristic data for the specimens of *Gekko liboensis*. Mean $\pm$ SD and range are shown. Abbreviations as in Materials and methods. Snout-vent length (SVL) and tail length (TL) data of adult males/females are shown in parentheses.

	<i>N</i>	Mean $\pm$ SD	Range
SVL (mm)	28	77.7 $\pm$ 6.96	65.9–91.0
	(17/11)	(77.1 $\pm$ 6.62/78.8 $\pm$ 7.35)	(65.9–87.0/68.3–91.0)
TL (mm)	18	80.5 $\pm$ 9.19	61.8–99.5
	(12/6)	(80.9 $\pm$ 7.65/79.7 $\pm$ 12.9)	(65.2–90.1/61.8–99.5)
IO	30	41.3 $\pm$ 1.90	38–46
DTR	31	8.32 $\pm$ 1.64	4–10
SPL	31	11.6 $\pm$ 0.882	10–13
IL	31	10.9 $\pm$ 0.814	10–13
IN	31	0.258 $\pm$ 0.514	0–2
SLI	31	13.5 $\pm$ 1.12	11–15
SLIV	31	14.1 $\pm$ 1.61	11–18
PP	17	10.5 $\pm$ 0.62	10–12
DB	31	8.68 $\pm$ 0.979	7–11
CB	19	8.16 $\pm$ 0.765	7–9

vs. *G. hokouensis* and *G. liboensis* vs. *Gekko* sp. 1; Figure 4). The range of PPs did not overlap between *G. liboensis* and *Gekko* sp. 1, but did overlap between *G. liboensis* and *G. hokouensis*.

3.5 Comparison with all other species belonging to the *G. japonicus* group The series of *Gekko* specimens described in the current study differed from all other 23 members of the *G. japonicus* group (*G. hokouensis*, *G.*

Table 3 Comparison of snout-vent length (SVL) and number of precloacal pores (PP) among *Gekko liboensis*, *G. hokouensis*, and *Gekko* sp. 1. according to four references and this study. *N* indicates the total number of individuals. Data from juveniles were removed from that of Zhao *et al.* (1999) and this study.

	Locality	SVL (mm)			PP			Reference
		<i>N</i>	mean	range	<i>N</i>	mean	range	
<i>Gekko liboensis</i>	Southern China	28	77.7	65.9–91.0	18	10.4	10–12	this study
	Southern China (Guizhou)	3	–	76–85	–	–	–	Zhao <i>et al.</i> (1999)
<i>Gekko hokouensis</i>	Eastern China	108	–	51–70	–	–	–	Zhao <i>et al.</i> (1999)
	Eastern China (Zhejiang)	16	62.78	–	–	–	–	Zhang <i>et al.</i> (2009)
	Taiwan	87	54.1	42.8–63.0	41	7.8	6–10	Ota <i>et al.</i> (1989)
	Japan	170	–	up to 56.4	70	–	6–10	Toda (2008)
<i>Gekko</i> sp. 1	Japan	117	–	up to 73.3	52	–	4–8	Toda (2008)

japonicus, *G. tawaensis*, *G. yakuensis*, *G. vertebralis*, *G. shibatai*, *G. swinhonis*, *G. auriverrucosus*, *G. melli*, *G. scabridus*, *G. subpalmatus*, *G. palmatus*, *G. chinensis*, *G. taibaiensis*, *G. similignum*, *G. adleri*, *G. wenzianensis*, *G. canhi*, *G. truongi*, *G. scientiadventura*, *G. aaronbaueri*, *G. thakhekensis*, and *Gekko* sp. 1) except for *G. auriverrucosus*, *G. melli*, *G. scabridus*, *G. subpalmatus*, and *G. truongi* by having 10–12 PPs. Moreover, the form was distinguished from *G. auriverrucosus* by a lower number of DTRs (4–10 vs. 16–20), absence of tubercles on the hind limbs, and a lower number of cloacal spurs (1 vs. 2–3); from *G. melli* by the presence of tubercles on the dorsum and undeveloped interdigital webs; from *G. scabridus* by a lower number of DTRs (4–10 vs. 17–21), and the presence of tubercles on the dorsal surface of the tail and the four limbs; from *G. subpalmatus* by the presence of tubercles on the dorsum and undeveloped interdigital webs; and from *G. truongi* by the presence of tubercles on the dorsum. In summary, the present form can be distinguished from all other members of the *G. japonicus* species group by more than one characteristic.

4. Discussion

To be best of our knowledge, our specimens are the third reported collection of *G. liboensis* following Zhou and Li (1982) and Zhao *et al.* (1999) and the first report of male specimens of the species. The comparisons with all other members of the *G. japonicus* group well support the taxonomic validity of *G. liboensis*. Morphologically, *G. liboensis* is most similar to *G. hokouensis* and *Gekko* sp. 1, a cryptic species of *G. hokouensis*. Despite some overlapping key character states, there are significant differences among these three species. In summary, *G. liboensis* can be reliably distinguished from *G. hokouensis* and *Gekko* sp. 1 by the presence of the following features: (1) a larger body size (65–91 mm in SVL [vs. 43–56 mm in *G. hokouensis* and 43–73 mm in *Gekko* sp. 1]); (2) an usual absence of IN (vs. usually present in the latter two

species); (3) 4–10 DTRs (vs. 12–18 in *G. hokouensis* but data absent in *Gekko* sp. 1); (4) 10–12 PPs (vs. 6–10 in *G. hokouensis* and 3–8 in *Gekko* sp. 1); and (5) the presence of conspicuous white marks on the dorsum and head (vs. absence in the latter two species). Further studies by use of molecular techniques are desirable to verify our conclusion.

Our specimens of *G. liboensis* were collected from Libo and Maolan in Guizhou and Nalao in Guangxi, with those in Nalao the first report of the species from outside Guizhou. At Nalao we also found eggs of large size (the mean diameters along the long and short axes are 16.3 and 12.4 mm, respectively), where another gekkonid species, *Hemiphyllodactylus dushanensis*, has also been recorded (Zhou *et al.*, 1981; Grismer *et al.*, 2013). In comparison with the diameters along the long and short axes of the eggs of *H. dushanensis* (8.7–9.2 mm and 6.7–6.8 mm, respectively; Zhou *et al.*, 1981), it is almost certain that the eggs we found at Nalao are of *G. liboensis*.

All specimens and the eggs were found on rocky outcrops in karstic mountains or hills, suggesting that such landscape that provides good shelter and suitable oviposition sites is a preferred habitat of the species *G. liboensis*. This kind of landscape continues around eastern Yunnan, Guizhou, and western Guangxi in southern China. Although the distribution range of *G. liboensis* requires clarification by further field survey, it is likely that the distribution of *G. liboensis* occurs more widely than is currently known. In contrast, during the current decade, a number of gecko species have been described from karstic outcrops and caves at single or a few localities in East and Southeast Asia (e.g., Ngo and Bauer, 2008; Ngo *et al.*, 2009; Linkem *et al.*, 2010; Ngo and Gamble, 2010, 2011; Ziegler and Nguyen, 2010; Grismer *et al.*, 2014). In these regions, the erosion of karstic area has resulted in isolated karstic mountains and hills that are surrounded by alluvial plains that are not suitable habitat for the geckos (Ellis and Pauwels, 2012). This isolated distribution of potentially suitable habitat

is likely to result in several local endemics. Further surveys of unexplored karstic mountains and hills and the comprehensive phylogenetic study of the *Gekko japonicus* group are required to understand the actual diversity of this group.

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Appendix 1 Catalogue numbers of specimens used in this study.

Gekko liboensis: CIB101225–101255 (101225–101236 for gonadal observation).

Gekko hokouensis: KUZ R30416–30422, 30471, 30473–30476, 30514–30521, 30570, 30571, 30573, 30574, 30600, 30601, 31172–31185, 31202, 31203, 31238–31242, 32257–32261, 32269–32275, 32309, 32310, 32323–32330, 32347, 32348, 32447, 32453, 32456–32459, 33336–33340, 33534–33539, 33631–33636, 34141, 34142, 45368, 45369, 45559–45561, 45563–45566, 47348–47351, 47355, 47357–47361, 47363, 47366–47369, 47371–47376, 47554–47565, 47567, 47568, 47570, 47571, 47573–47584, 47740–47745, 48071–48074, 48081–48086.

Gekko sp. 1: KUZ R30415, 30472, 30550–30559, 30572, 30575–30577, 31228, 31229, 32158–32161, 32263, 32264, 32266, 32268, 32314–32316, 32443–32446, 32448–32452, 32454, 32455, 32995–32998, 33269, 33270, 33297, 33299, 33300, 33540, 33541, 33573–33576, 34147–34150, 34214–34219, 34259–34266, 34558–34569, 45319–45321, 45325, 45327, 45330, 45371, 45463, 47370, 47377–47382, 47585–47596, 47736–47739, 50137.